IAC-17-B2.5.10

In-Situ Navigation and Timing Services for a Human Mars Landing Site[1]

Part 1: System Concept

Kar-Ming Cheung, Charles Lee

Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Ave., Pasadena, CA 91109

September 25-29, 2017

[1] Part of this work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Abstract

In [1] and [2], we introduce a new geometric trilateration method that simultaneously performs absolute positioning and relative positioning. The relative position is derived from a "differencing" function of two raw-range measurements between a known reference point and of the target from a navigation satellite, thereby eliminating most of the common errors like atmospheric delays, ephemeris errors, and instrument delays in real-time. In the Mars environment this "error-cancellation" function greatly reduces the need to perform extensive orbit determination (OD) of the navigation satellites like the Earth's GPS, and only requires occasional tracks from the Earth's large-aperture deep space antennas to perform OD's. Leveraging on this scheme, we propose a low-cost, low-maintenance regional navigation satellite system architecture that provides in-situ navigation and timing services for robotic and human missions in the vicinity of a Mars landing site.

This architecture is built upon the proposed Mars relay network infrastructure, and a number of notional Mars orbiting and surface missions in the human exploration era of Mars. We assume two areostationary Mars relay orbiters that have continuous line-of-sight visibility with the Mars landing site, a Deep Space Habitat (DSH) in an inclined 48-hour circular orbit, and a surface communication lander that could serve as the reference point. These orbiting and surface infrastructure elements broadcast GPS-like ranging signals and other ephemeris information to the mission users. With one or more additional orbiters in areosynchronous orbits that trace around a figure-8 path, a regional navigation satellite system can be realized that provides in-situ course absolute localization and precision relative localization and timing services to the users in the vicinity of a Mars landing site.

This paper describes the system concept of the proposed Mars regional navigation satellite system.

1. Introduction

Human Mars explorations require substantial build-up of orbiting and surface infrastructures on Mars. In addition to communication coverage, location awareness is essential to supporting various human and robotic activities on the Mars surface and on orbit. This could include localizing discoveries and returning to sites, construction/assembly of structures and habitats, entry/descent/landing, approach/rendezvous/docking, Mars ascent, and orbit insertion, etc.

A Mars relay orbiter network with dedicated communications and navigation satellites has been proposed in various studies [3][4][5] to support the communication and navigation needs. As the initial Mars exploration activities are expected to be confined in the vicinity (within 100 kilometers) of a Mars landing site, a favorable Mars relay network architecture option is to have two areostationary orbiters that are within the line-of-sight of the landing site, and yet have enough angular distance such that at least one of the orbiters would be able to provide continuous communication coverage to the landing site during solar conjunction events. A deep space habitat (DSH) has also been proposed, which would orbit around Mars in an inclined 48-hour circular orbit. The DSH would act as a staging and monitoring facility for the human Mars surface explorations, and to perform tele-robotic activities on Mars, Phobos, and Demos. We propose to leverage on the planned build-up of the Mars infrastructure elements–with the addition of one or more low-cost dedicated Mars navigation satellites that trace around a figure-8 path in areosynchronous orbits–to build a Mars Regional Navigation Satellite System (MRNSS) that would provide continuous or near-continuous in-situ navigation and timing services for the robotic and human missions in the vicinity of the Mars landing site.

This network concept bears resemblance to the Indian Regional Navigation Satellite System (IRNSS)

[6], which consists of three navigation satellites in the Earth's geostationary orbits and four navigational satellites in geosynchronous orbits. The IRNSS provides continuous positioning and timing services to vehicles in the India and neighbouring region with an absolute positioning accuracy of 10 meters. Unlike the IRNSS, whose ground segment consists of four dedicated Earth's ground stations that perform 24/7 high-precision orbit determination (OD) measurements for the orbiting navigation satellites, the MRNSS has to rely on the large-aperture antennas from the deep space network (DSN) and other space agencies to perform Doppler, ranging, and possibly Delta-DOR measurements for OD. Note that the DSN is a shared resource for many deep space spacecraft, and its support can be highly contentious at times. Thus providing enough DSN tracking time to perform precision OD for four or more Mars orbiting navigation satellites can be challenging, if not impossible. In later Sections, we discuss a proposed system design and an operation concept that could alleviate this problem.

The rest of the paper is organized as follows: Section 2 discusses the challenges of positioning and navigation on Mars, and proposes a number of novel approaches to build up a low-cost, low-maintenance Mars navigation infrastructure. Section 3 reviews prior work on a new geometric trilateration scheme [1] [2]. The new scheme executes the same computational procedures to estimate absolute position and relative position. Only the inputs to the algorithm are different. Thus, the same software or hardware implementation can be used for both applications. Section 4 provides the problem formulation, and derives the relative positioning algorithm for orbiting and surface vehicles on Mars. Section 5 describes the proposed MRNSS constellation that leverages on the two planned areostationary relay orbiters and the DSH in a circular 2-SOL inclined orbit, and augmented with a navigation satellite in a areosynchronous orbit that traces around a figure-8 path. Section 6 provides concluding remarks and discusses future work.

2. Challenges of Positioning and Navigation on Mars and Possible Solutions

Currently the navigation of all spacecraft to Mars, whether science orbiters or landing assets, is performed using the large antennas from NASA's DSN or ESA's European Space Tracking (ESTRACK) network. These antennas provide tracking and navigation support to a few dozen of the deep space spacecraft across the Solar System by performing 2-way Doppler, ranging, and occasional Delta-DOR measurements at the ground stations on Earth. These measurements are then processed to generate estimates on spacecraft position and velocity. In the human Mars era, the traditional deep space tracking and navigation approach faces the following challenges:

1. As the orbiting and surface elements build up in the vicinity of the Mars landing site, the traditional methods that require pairing one dedicated ground station with one spacecraft for a period of time to generate tracking measurements becomes impractical. This is due to a large number of flight assets in the same vicinity.
2. The Earth-based tracking approach is limited by the speed of light. As a spacecraft travels further from Earth, the communication lag time due to the finite speed of light increases. At Mars distance, this lag time, also known as one-way-light-time (OWLT), is between 4 and 24 minutes. During the final and critical phase of Mars approach when the spacecraft is about to enter the Martian atmosphere, the ground network would not be able to provide navigation updates to the spacecraft at least OWLT prior, and the spacecraft would have to continue its descent along the last trajectory update received from the ground.

It is therefore desirable to have a Mars local navigation infrastructure that provides real-time in-situ navigation and timing services to the orbiting and surface assets. In the early phase of human Mars missions, it is envisioned that the exploration activities would not extend beyond 100 kilometers of the Mars landing site. A prime candidate of the landing site is Utopia Planitia, which is in the Mars Northern mid-latitude.

Taking into account the need to provide only regional coverage on the Mars surface, and the expected deployment of areostationary relay orbiters and other orbiting assets that hover over the Mars landing site, we propose to leverage on the Mars orbiting infrastructure build-up to establish a Mars Regional Navigation Satellite System (MRNSS). With the augmentation of one or more low-cost dedicated Mars navigation satellites that trace around a figure-8 path in areosynchronous orbits, there can be 4 or more navigation nodes with sufficient geometric diversity that could enable accurate localization in the vicinity of the Mars landing site.

To provide accurate Mars surface positioning, the MRNSS requires precision orbit determination (OD) of the orbiting Mars navigation nodes. Unlike Earth's GPS and IRNSS constellations that have dedicated ground stations performing real-time 24/7 high-precision OD measurements, the navigation nodes in MRNSS have to rely on the shared antennas of the DSN and other space agencies. For a Mars orbiter, there are natural forces that tend to shift the spacecraft from its ideal trajectory predicted by the Kepler's Laws. The dominant factors are perturbations due to the non-spherical mass distribution of the Mars gravitational field, and the gravitational attraction of the Sun, Phobos, and Deimos moons. Solar radiation pressure also contributes to the disturbances. It is shown in [7] that long and continuous or near-continuous DSN tracking for 2 to 4 days is required to yield 10+ meters of OD errors for a Mars areostationary orbiter. This would translate into 10's or 100's of meters of localization error when the Earth-style GPS localization method is used. Apart from tying up most of the DSN antenna resource to perform OD, this level of localization accuracy is insufficient for many activities for the orbiting and surface Mars assets.

Toward this end, we propose the following novel architecture concepts that would reduce the ground antenna tracking time to perform OD for multiple Mars navigation satellites:

1. Relative positioning instead of absolute positioning–range measurements needed to perform GPS-style absolute positioning[2] include different kinds of errors–random measurement error, media error when signal passes through an atmosphere, clock bias between the spacecraft and the navigation satellite, and the ephermeris error of the navigation satellite, etc. However, if the spacecraft is in the close vicinity of a reference point, range measurement between the spacecraft and a navigation satellite, and that between the reference point and the same navigation satellite, contain much of the same common errors. As we will show in later sections, much of these common errors could be "canceled out" in the estimation of relative position, thus reducing the OD accuracy requirements on the navigation satellites.
2. Simultaneous ranging for multiple spacecraft – the traditional approach of tying up one ground antenna to one Mars orbiter to perform 2-way Doppler and ranging measurements can be problematic when there are 4 or more Mars orbiters that requires OD tracking support. We assume ranging is done in X-band, which also supports low-rate command and telemetry. At Mars distance, the Mars orbiters all lie within the same X-band beamwidth of a DSN 34-m BWG antenna. For *N* Mars orbiters, the downlinks operate in *N* allocated frequency bands separated by *N-1* guard bands to prevent interferences. In general, the *N* orbiters exhibit different downlink Doppler and Doppler rate signatures. Here we outline a low-cost approach that rides on the recently proposed Multiple Uplink per Antenna (MUPA) concept [8], and would require the following onboard and ground changes to enable simultaneous 2-way ranging for multiple spacecraft.

   a. The *N* spacecraft time-share a single uplink frequency–each spacecraft receives and tracks the same Doppler-compensated uplink signal. Individual spacecraft uplink commands and data loads are differentiated by spacecraft ID.
   b. The ground "Doppler-compensates" the uplink signal in either one of the following ways: i) with respective to the Mars center, or ii) with respect to the average of Doppler profiles of the *N* orbiters. The downlink guard bands have to be wide enough to accommodate the residual Dopplers between the frequency-adjacent orbiters. Using the MRNSS scenario discussed in this paper, preliminary results show that the residual Doppler and residual Doppler rate are bound by 40 KHz and 2.6 Hz/s respectively [9].
   c. On the spacecraft side, the radio would require the following upgrades: i) A different turn-around-ratio for each spacecraft so that the same Doppler-compensated uplink signal received by each spacecraft would be coherently "turned-around" to modulate the telemetry and ranging signals on a different downlink frequency. ii) A well-designed tracking loop that can sweep, acquire, and track the unknown uplink carrier phase and residual Doppler frequency. A preliminary design of this type of tracking loop was introduced in [10] to track a constellation of 20 spacecraft in a halo orbit around the Earth-Moon Lagrange Point L1.

   For now, the aforementioned high-level discussion on simultaneous ranging does not assume any specific ranging schemes, e.g. sequential ranging, Pseudo-random Noise (PN) ranging, and PN regenerative ranging, etc. Next, we plan to consider the pros and cons of different ranging techniques for simultaneous ranging. We also want to investigate and to characterize this approach in greater detail, and to report the findings in a future paper [9].
3. New geometric trilateration schemes for simultaneous relative positioning and absolute

[2] With respect to Mars center.

positioning–we introduce a new geometric trilateration scheme in [1] and [2], and can perform simultaneous relative positioning and absolute positioning. This scheme is an important building block for the above low-cost low-maintenance Mars in-situ navigation architecture. We provide an overview of this trilateration scheme in the next section.

The architecture of the proposed MRNSS is depicted in Figure 1.

trilateration scheme is that it exercises a differencing function on raw range measurements of the reference spacecraft and the target spacecraft, thereby eliminating most of the atmospheric delay errors in the measurements. We showed that this scheme could achieve meter-level accuracy (sub-meter in some cases) in the presence of reasonable measurement errors, clock biases, ephemeris errors, and atmospheric delays. The iterative procedure that computes the relative position is outlined in Figure 2.

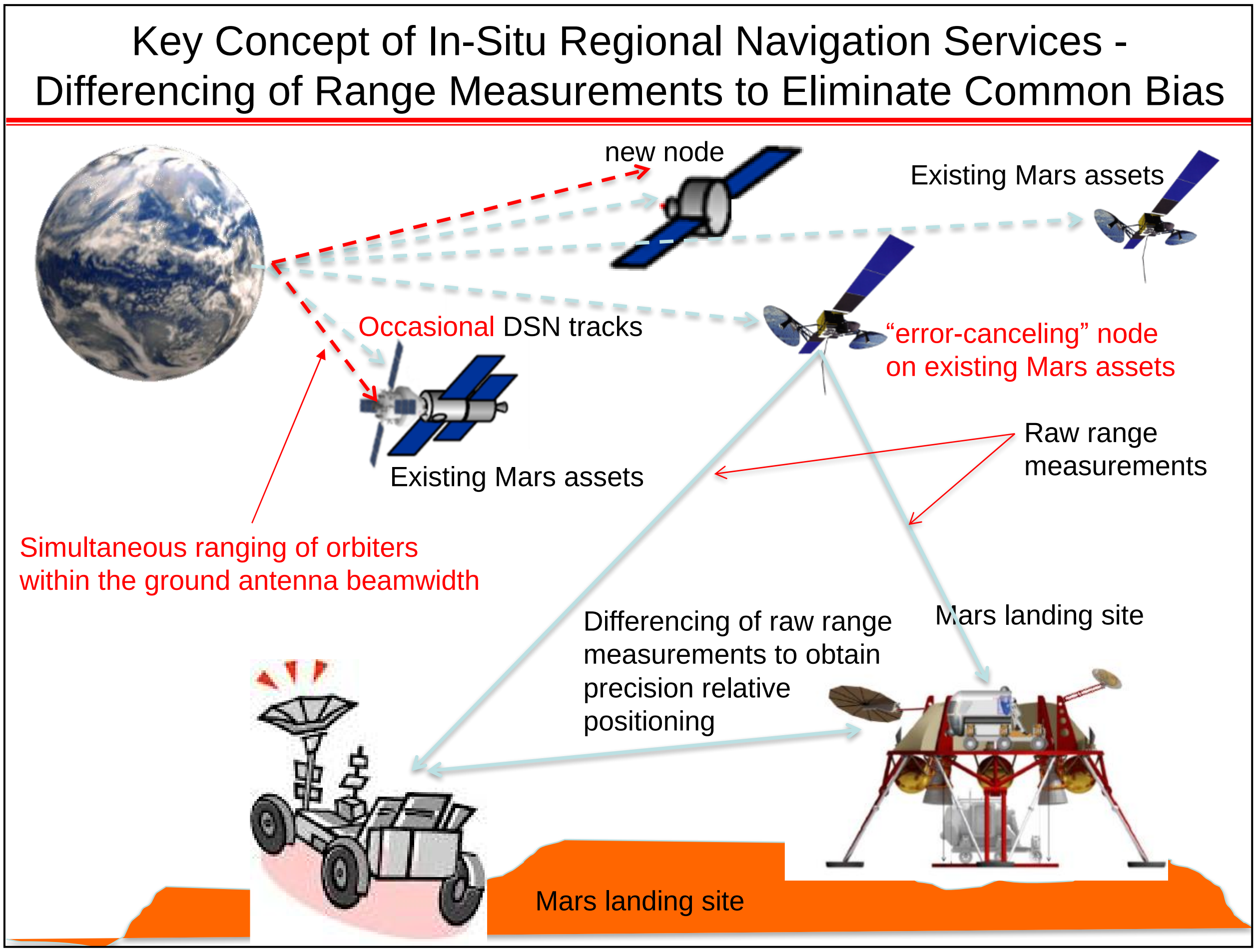

Fig. 1. Schematic of MRNSS Architecture

3. Review of Prior Work on the New Geometric Trilateration (GT) Scheme

In [1] we introduce a trilateration scheme that evaluates the 3-dimensional (3-D) relative position using an example of three or four ground stations "looking upward," and tracking a constellation of spacecraft that is composed of one reference spacecraft and multiple target spacecraft operating at the geosynchronous orbit (GEO). We assume that the reference spacecraft's clock is perfectly synchronized with the ground clock. A unique feature of the

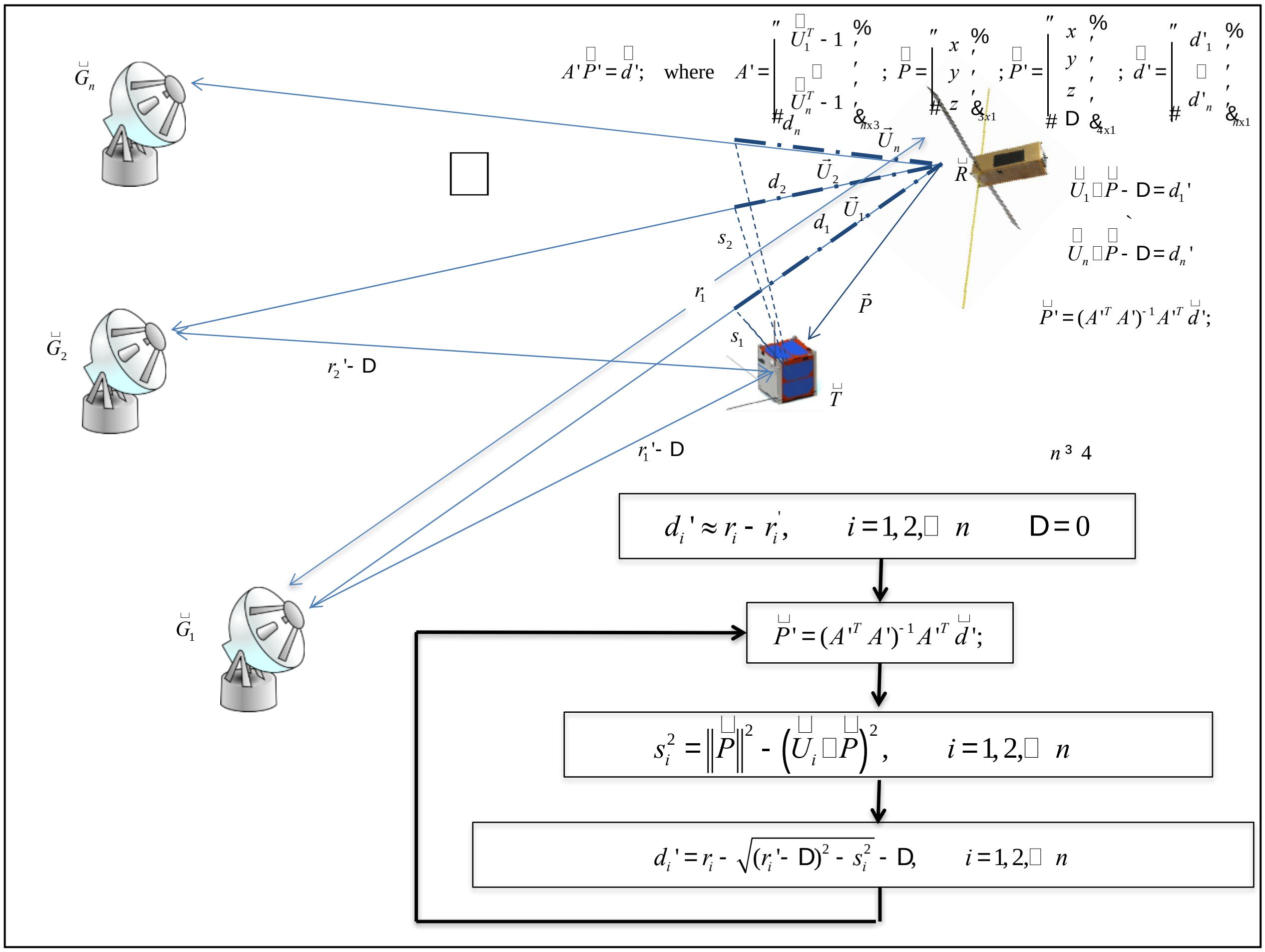

Fig. 2. Iterative Procedure of the GT Scheme for Relative Positioning

We use a similar problem formulation approach to derive a GPS-style absolute localization in [2], and we provide detailed computation and accuracy performance analysis of the GT scheme for absolute positioning in [11]. Traditional GPS trilateration scheme uses Newton-Raphson's method that performs linear regression to coverage to a localization solution [12]. The new scheme applies Pythagoras' Theorem to a pair of right-angled triangles constructed from a GPS satellite, the Earth's center, and the vehicle, and iteratively solving for the localization solution. We show that both the Newton-Raphson's method and the Pythagoras' method yield indistinguishable localization accuracy under the same error conditions. The iterative procedure that computes the absolute position is shown in Figure 3. It can be shown that the trilateration scheme for GPS-style absolute positioning executes the same computation procedures as that for relative positioning. Only the inputs to the algorithm are different. Thus the same software or hardware implementation can be used for both applications.

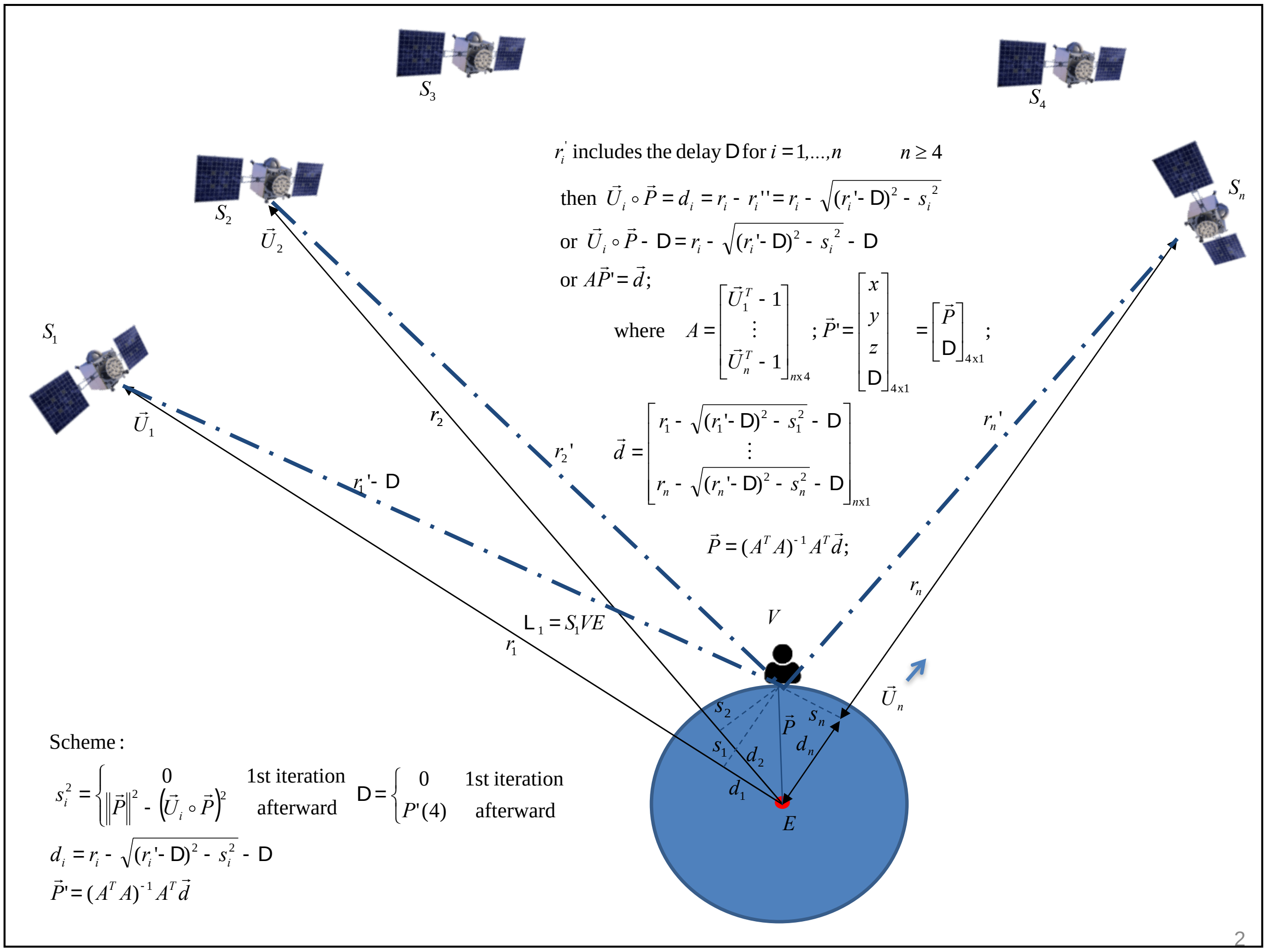

Fig. 3 Iterative Procedure of the GT Scheme for Absolute Positioning

4. Relative Positioning on Mars Surface

In this paper, we consider the scenario of four Mars navigation satellites "looking downward" to perform relative positioning between a Mars surface lander (the reference) and another Mars vehicle (the target) moving in the vicinity of the Mars lander. In this case, we assume that both the lander and the moving vehicle are not synchronized with the navigation satellites' clock, and have different clock biases.

Without loss of generality, we assume V_1 to be the "reference" lander, and V_2 to be the "target" Mars vehicle. The impact of the choice of "reference" and "target" between the two vehicles is discussed in the next section.

We use the same terminologies as in [1] but with a few exceptions. We replace ground antenna locations $\vec{G}_i$ with Mars satellite positions $\vec{S}_i$, and we denote the locations of the reference lander and the target vehicle $\vec{R}$ and $\vec{T}$ respectively. For Mars satellite $\vec{S}_1$, $\vec{S}_1$, $\vec{R}$ and $\vec{T}$ form a triangle Δ_1 in the Euclidean space as shown in Figure 4. We assume that the coordinates of $\vec{R}$ and $\vec{T}$ are not precisely known. Let r_1 and r_1' be the raw-range measurements between $\vec{S}_1$ and $\vec{R}$, and between $\vec{S}_1$ and $\vec{T}$, respectively. We define raw-range as the range that includes all the systematic errors that occur during range measurements. We express the unknown clock bias of the target vehicle $\vec{T}$ with respect to $\vec{R}$ as an unknown correction factor Δ[3] in the raw-range measurements of $\vec{T}$.

[3] $\Delta = c\delta t$, where c is the speed of light, and δt denotes the clock bias.

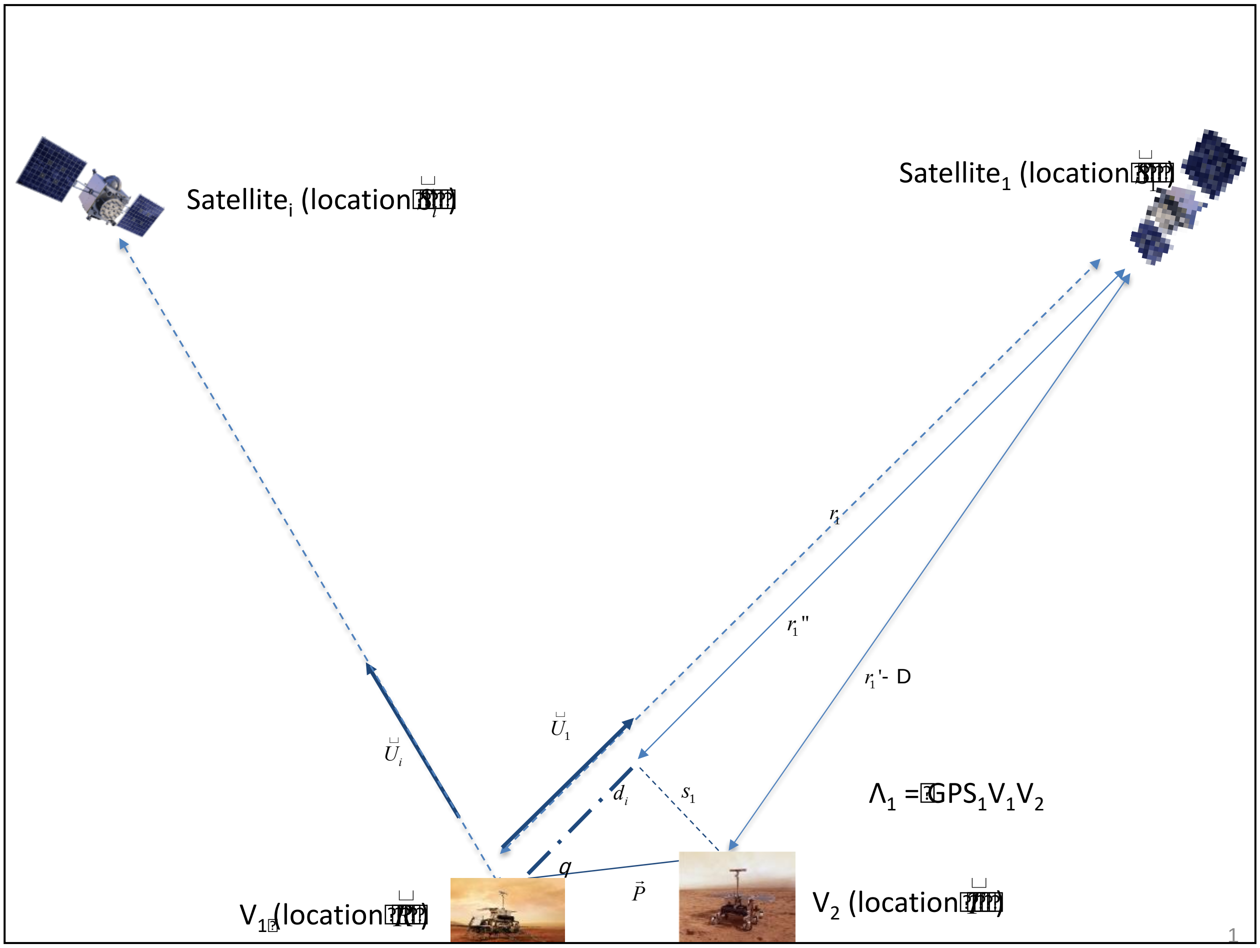

Fig. 4. Geometry of Relative Positioning on Mars Surface

Let $\vec{U}_1 = \begin{pmatrix} u_{x1} \\ u_{y1} \\ u_{z1} \end{pmatrix}$ be the directional cosine of $\vec{R} - \vec{S}_1$, which we assume to know to a reasonable degree of accuracy (discussed further in Section 3), and let $\vec{P} \cong \vec{T} - \vec{R} = \begin{pmatrix} p_x \\ p_y \\ p_z \end{pmatrix}$ be the relative position vector of interest.

We assume $r_1 >> \left\|\vec{P}\right\|$,[4] and $r_1' >> \left\|\vec{P}\right\|$. Let s_1 be the altitude of Λ_1 through $\vec{T}$. Denote the projection of $\vec{P}$ onto $\vec{R} - \vec{G}_1$ to be d_1, which can be expressed as the dot product between $\vec{U}_1$ and $\vec{P}$ (denoted by $\vec{U}_1 \circ \vec{P}$). Note that Λ_1 is made up of two right-angled triangles that share a common side s_1, where $s_1 \le \left\|\vec{P}\right\|$. We construct the following relationships by applying Pythagoras' Theorem on the two right-angled triangles in Λ_1 of Figure 1:

$$s_i^2 = \left\|\vec{P}\right\|^2 - \left\|\vec{U}_i \circ \vec{P}\right\|^2 \qquad \text{(1a)}$$

[4] $\left\|\vec{P}_1\right\|$ denotes the magnitude of $\vec{P}_1$

$$d_i = r_i - ((r_i' - \Delta)^2 - s_i^2)^{\frac{1}{2}} \tag{1b}$$

For n = 4, we define the vector $\vec{P}' = \begin{bmatrix} p_x \\ p_y \\ p_z \\ \Delta \end{bmatrix}$, the matrix $A' = \begin{bmatrix} \vec{U}_1^T & -1 \\ \vec{U}_2^T & -1 \\ \vec{U}_3^T & -1 \\ \vec{U}_4^T & -1 \end{bmatrix}$, and $\vec{d}' = \begin{bmatrix} d_1 - \Delta \\ d_2 - \Delta \\ d_3 - \Delta \\ d_4 - \Delta \end{bmatrix}$ such that

$$\vec{P}' = (A')^{-1}\vec{d}' \tag{2}$$

As in Section 2, equation (7) forms an iterative relationship with equations (6). In general when there are n anchors, where $n \geq 4$, one can form additional Pythagorean relationships as shown in the above equations, and compute the least mean square solution of an over-determined system as follows:

$$A' = \begin{bmatrix} \vec{U}_1^T & -1 \\ \vec{U}_2^T & -1 \\ \vdots & \\ \vec{U}_n^T & -1 \end{bmatrix}_{nx4} \text{ and } \vec{d}' = \begin{bmatrix} d_1 - \Delta \\ d_2 - \Delta \\ \vdots \\ d_n - \Delta \end{bmatrix}$$

$$\vec{P}' = (A'^T A')^{-1} A'^T \vec{d}' \tag{3}$$

Based on the above formulation, we construct an iterative method that guarantees convergence to the relative position vector $\vec{P}'$ using raw-range measurements of $r_1, r_2, \ldots, r_n$ and $r_1', r_2', \ldots, r_n'$, where $n \geq 4$. We outline the method for the case n = 4:

Iterative Procedure:

1. Initialization:
   a. Compute the directional cosines $\vec{U}_1$, $\vec{U}_2$, $\vec{U}_3$, and $\vec{U}_4$, and construct the matrix *A'*.
   b. Set $s_1 = s_2 = s_3 = s_4 = 0$.
   c. Set $\Delta = 0$.
   d. Compute $M' = A'^{-1}$ (or $M' = (A'^T A')^{-1} A'^T$ for $n \geq 5$)
2. Compute d_1, d_2, d_3, and d_4 according to equations (1b).
3. Compute $\vec{P}' = M'\vec{d}'$ according to equation (2).
4. Compute s_1^2, s_2^2, s_3^2, and s_4^2 according to equations (1a).
5. Go to 2, and compute $\vec{P}'$ until $\vec{P}'$ converges.

Note that in the above iterative procedure, the matrix *M'* only needs to be computed once at initialization and the same matrix *M'* is used for all subsequent iterations to coverage to a localization solution.

5. A Notional MRNSS Constellation

We consider the scenario of a human Mars landing site at Utopia Planitia on Mars, and propose a MRNSS constellation that provides regional navigation and timing services in the surrounding region of the landing site. The MRNSS constellation leverages on the two planned areostationary relay orbiters and the DSH in a circular 2-SOL inclined orbit, and augmented it with a navigation satellite in an areosynchronous orbit that traces around a figure-8 path. The orbits of the Mars navigation nodes are shown in Figure 5 (3-D view), and the projections of these orbits onto the Mars surface are shown in Figure 6 (2-D view). Note that in Figure 6 the Mars navigation nodes cluster together, and Utopia Planitia is north of the cluster. The satellite-receiver geometry appears to be weak and the geometric dilution of precision (GDOP) is high. In other words, the localization solution can be very sensitive to the errors in the raw-range measurements. In an upcoming paper (Part 2), we plan to perform in-depth simulations to evaluate and to compare the root-mean-square-error (RMSE) performance of the absolute and relative positioning schemes using the MRNSS constellation scenarios under different combinations of error conditions: 3-D ephermeris errors of the navigation satellites, random pseudo-range measurement errors, and clock biases of the reference spacecraft and the target spacecraft.

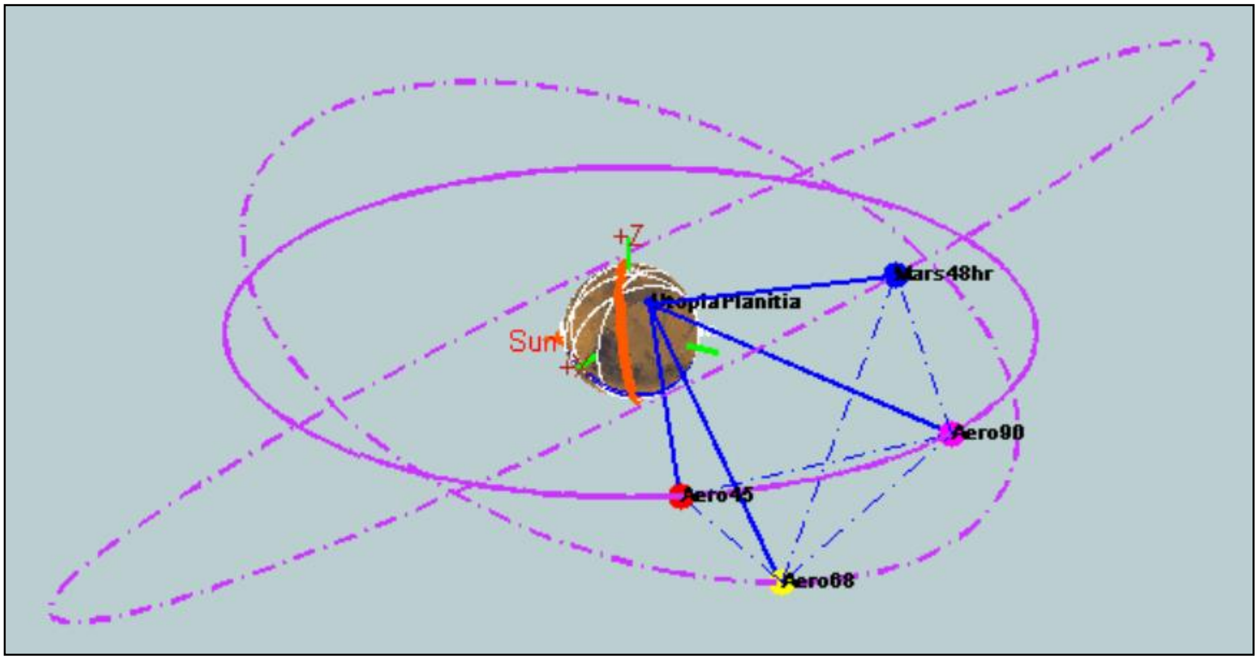

Fig. 5. Orbits of the Notional Mars Navigation Nodes (3-D View)

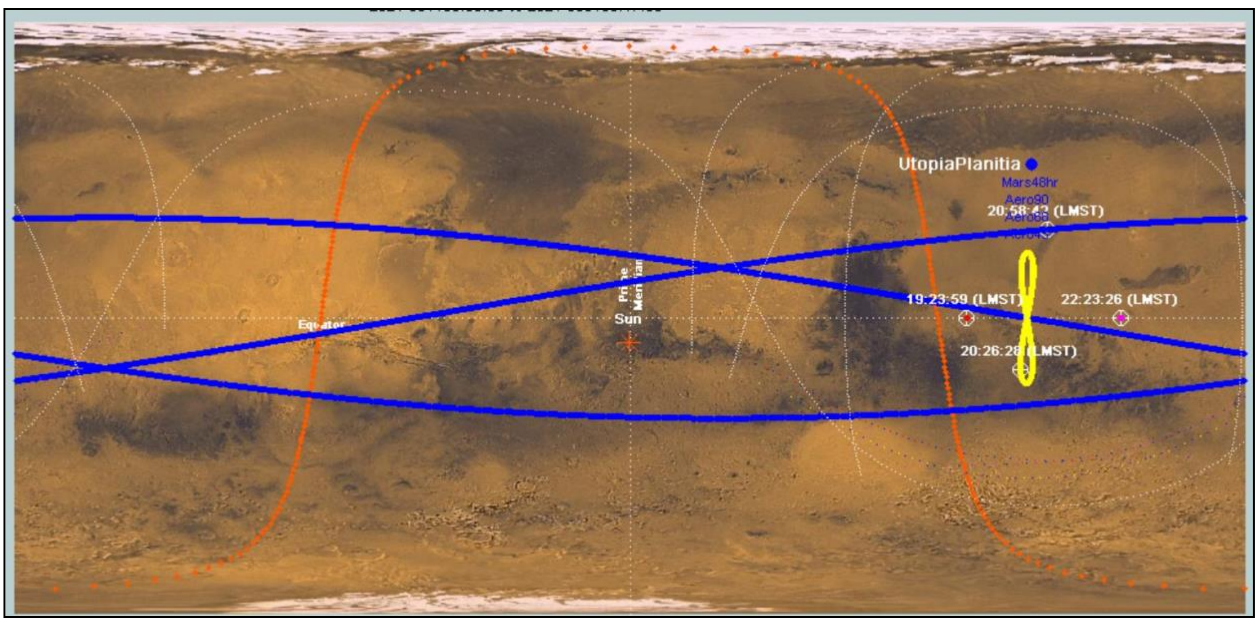

Fig. 6. Orbits of the Notional Mars Navigation Nodes (2-D View)

6. Concluding Remarks and Future Work

In this paper, we propose a low-cost, low-maintenance regional navigation satellite system architecture that would provide in-situ navigation and timing services for the robotics and human missions in the vicinity of the Mars landing site. We introduce a new geometric trilateration scheme [1][2] that simultaneously performs absolute and relative localization, and formulate a system concept that leverages on the substantial build-up of orbiting and surface infrastructures on Mars to construct a Mars Regional Navigation Satellite System (MRNSS).

We illustrate the system concept using the scenario of four Mars orbiters "looking downward" to perform relative positioning between a reference station at the Mars landing site and a moving vehicles in the vicinity of the site. Note that in the above discussion we do not assume the use of any advanced GPS measurement techniques, signal-processing algorithms, and location-specific meteorological measurements to estimate the atmospheric delays and differentials. We believe that if we were to implement this scheme using the current state-of-the-art GPS capabilities, we could achieve a considerably better accuracy performance than what we show in this paper.

In an upcoming paper (Part 2), we plan to perform in-depth simulations to evaluate the root-mean-square-error (RMSE) performance of the absolute and relative positioning schemes discussed in in Sections 2 and 3 under different combinations of error conditions: 3-D ephermeris errors of the navigation satellites, random pseudo-range measurement errors, and clock biases of the reference spacecraft and the target spacecraft. Also, we will perform detailed analysis to derive mathematical insights as to how the trilateration algorithm would "cancel out" in real-time most of the common errors.

Acknowledgements

The authors would like to thank Professor Glenn Lightsey, of Georgia Tech, for the helpful technical support and discussion.

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The research was supported by NASA's Space Communication and Navigation (SCaN) Program.

References

[1] K.Cheung, C. Lee, A Trilateration Scheme for Relative Positioning, IEEE Aerospace Conference 2017, Big Sky, Montana, March 2017.

[2] K. Cheung, C. Lee, A Trilateration Scheme for GPS-Style Localization, Interplanetary Network Progress Report, 42-209, May 15, 2017.

[3] H. Price, J. Baker, F. Naderi, A Scenario for a Human Mission to Mars Orbit in the 2030s: Thoughts Toward an Executable Program – Fitting Together Puzzle Pieces & Building Blocks, Jet Propulsion Laboratory, California Institute of Technology. Presented at the Future In-Space Operations (FISO) Telecon, May 20, 2015.

[4] Mars Architecture Steering Group, Human Exploration of Mars Design Reference Architecture 5.0, Technical Report, NASA, 2009.

[5] D. Bell, R. Cesarone, T. Ely, C. Edwards, S. Townes, MarsNet: A Mars Orbiting Communications & Navigation Satellite Constellation, IEEE Aerospace Conference 2000, March 2000, Big Sky, Montana.

[6] R. Shriwas, R. Bele, R. Kalaskar, P. Jaiwsal, Indian Regional Navigation Satellite System, International Journal of Research In Science & Engineering, Special Issue: Techno-Xtreme 16, April 2016.

[7] P. Romero, B. Pablos, G. Barderas, Analysis of Orbit Determination from Earth-Based Tracking for Relay Satellites in a Perturbed Areostationaryh Orbit, Acta Astronautica 136 (2017) 434-442, April 4, 2017.

[8] D. Abraham, B. MacNeal, D. Heckman, Enabling Affordable Communications for the Burgeoning Deep Space CubeSat Fleet, SpaceOps 2016, May 2016, Daejeon, Korea.

[9] K. Cheung, D. Divsalar, S. Bryant, C. Lee, Simultaneous 2-Way Doppler and Ranging for Multiple Spacecraft at Mars, abstract submitted to SpaceOps 2018, May 2018, Marseille, France.

[10] A. Babuscia, D. Divsalar, K. Cheung, C. Lee, CDMA Communication System Performance for a Constellation of CubeSats around the Moon, IEEE Aerospace Conference 2016, March 2016, Big Sky, Montana.

[11] K. Cheung, G. Lightsey, C. Lee, Accuracy/Computation Performance of a New Trilateration Scheme for GPS-Style Localization, abstract submitted to IEEE Aerospace Conference 2018, March 2018, Big Sky, Montana.

[12] B. Kumar, Determination of GPS Receiver Position Using Multivariate Newton-Raphon Technique for Over Specified Cases, International Journal of Applied Engineering Research, vol. 3, no. 11, pp. 1457-1460, 2008.